IN THE CLAIMS

LISTING OF CLAIMS

Claim 1 (withdrawn): A method of tracking the orientation of a sensor, the method comprising:

a) measuring an angular velocity of the sensor to generate angular rate values;

b) integrating the angular rate values;

c) normalizing the integrated angular rate values to produce an estimate of sensor orientation;

d) measuring a magnetic field vector to generate local magnetic field vector values;

e) measuring an acceleration vector to generate local gravity vector values; and

f) correcting the estimate of sensor orientation using the local magnetic field vector and local gravity vector.

Claim 2 (withdrawn): A method of tracking as in Claim 1 wherein correcting the estimate of sensor orientation using the local magnetic field vector and local gravity vector comprises:

g) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

h) calculating a computed measurement vector from the estimate of sensor orientation;

i) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

j) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate;

k) integrating the error estimate;

l) normalizing the integrated error estimate to produce a new estimate of sensor orientation; and

m) repeating steps a)-m), wherein the new estimate of sensor orientation is used for h), calculating a computed measurement vector until tracking is no longer desired.

Claim 3 (withdrawn): The method of Claim 2 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function comprises minimizing the criterion function without calculating the criterion function.

Claim 4 (withdrawn): The method of Claim 2 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error.

Claim 5 (currently amended): ~~The method of Claim 4 wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements~~.

A method of tracking the orientation of a sensor, the method comprising:

a) measuring an angular velocity of the sensor to generate angular rate values;

b) integrating the angular rate values;

c) normalizing the integrated angular rate values to produce an estimate of sensor orientation;

d) measuring a magnetic field vector to generate local magnetic field vector values;

e) measuring an acceleration vector to generate local gravity vector values; and

f) correcting the estimate of sensor orientation using the local magnetic field vector and local gravity vector.

wherein correcting the estimate of sensor orientation using the local

magnetic field vector and local gravity vector comprises:

g) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

h) calculating a computed measurement vector from the estimate of sensor orientation;

i) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

j) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate;

wherein the operation of performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error;

wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements;

k) integrating the error estimate;

l) normalizing the integrated error estimate to produce a new estimate of sensor orientation; and

m) repeating steps a)-m), wherein the new estimate of sensor orientation is used for h), calculating a computed measurement vector until tracking is no longer desired.

Claims 6 (withdrawn): The method of Claim 2 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function comprises using time weighted filtering.

Claim 7 (withdrawn): The method of Claim 2 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function comprises using a Gauss-Newton iteration.

Claim 8 (withdrawn): A method of tracking the orientation of a sensor, the method comprising:

a) measuring an angular velocity of the sensor to generate an angular rate quaternion;

b) integrating the angular rate quaternion;

c) normalizing the integrated angular rate quaternion to produce an estimated sensor orientation quaternion; and

d) measuring a magnetic field vector to generate local magnetic field vector values;

e) measuring an acceleration vector to generate local gravity vector values;

f) correcting the estimated sensor orientation quaternion using the local magnetic field vector and local gravity vector.

Claim 9 (withdrawn): A method of tracking as in Claim 8 wherein correcting the estimated sensor orientation quaternion using the local magnetic field vector and local gravity vector comprises:

g) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

h) calculating a computed measurement vector from the estimated sensor orientation quaternion;

i) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

j) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate quaternion;

k) integrating the error estimate quaternion;

l) normalizing the integrated error estimate quaternion to produce a new estimated sensor orientation quaternion; and

m) repeating steps a)-m), wherein the new estimated sensor orientation quaternion is used for h), calculating a computed measurement vector.

Claim 10 (withdrawn): The method of Claim 9 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function comprises minimizing the criterion function without calculating the criterion function.

Claim 11 (withdrawn): The method of Claim 9 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error.

Claim 12 (currently amended): ~~The method of Claim 10 wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements~~ A method of tracking the orientation of a sensor, the method comprising:

a) measuring an angular velocity of the sensor to generate an angular rate quaternion;

b) integrating the angular rate quaternion;

c) normalizing the integrated angular rate quaternion to produce an estimated sensor orientation quaternion; and

d) measuring a magnetic field vector to generate local magnetic field vector values;

e) measuring an acceleration vector to generate local gravity vector values;

f) correcting the estimated sensor orientation quaternion using the local magnetic field vector and local gravity vector;

wherein correcting the estimated sensor orientation quaternion

using the local magnetic field vector and local gravity vector comprises:

g) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

h) calculating a computed measurement vector from the estimated sensor orientation quaternion;

i) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

j) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate quaternion;

wherein the operation of performing a mathematical operation that results in the minimization of the criterion function comprises minimizing the criterion function without calculating the criterion function;

wherein the operation of performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error;

wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements;

k) integrating the error estimate quaternion;

l) normalizing the integrated error estimate quaternion to produce a new estimated sensor orientation quaternion; and

m) repeating steps a)-m), wherein the new estimated sensor orientation quaternion is used for h), calculating a computed measurement vector.

Claims 13 (withdrawn): The method of Claim 9 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function comprises using time weighted filtering.

Claim 14 (withdrawn): The method of Claim 9 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function comprises using a Gauss-Newton iteration.

Claim 15 (withdrawn): A method of tracking the orientation of a sensor, the method comprising:

a) providing a starting estimate of sensor orientation;

b) measuring a magnetic field vector to generate local magnetic field vector values;

c) measuring an acceleration vector to generate local gravity vector values;

d) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

e) calculating a computed measurement vector from the estimate of sensor orientation;

f) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

g) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate;

h) integrating the error estimate;

i) normalizing the integrated error estimate to produce a new estimate of sensor orientation; and

j) repeating steps a)-j), wherein the new estimate of sensor orientation is used for e), calculating a computed measurement vector.

Claim 16 (withdrawn): The method of Claim 15 wherein each new estimate of sensor orientation is output as a sensor orientation signal.

Claim 17 (withdrawn): The method of Claim 15 wherein the operation of g), performing a mathematical operation that results in the minimization of the

criterion function comprises minimizing the criterion function without calculating the criterion function.

Claim 18 (withdrawn): The method of Claim 15 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error.

Claim 19 (currently amended): ~~The method of Claim 18 wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements.~~

A method of tracking the orientation of a sensor, the method comprising:

a) providing a starting estimate of sensor orientation;

b) measuring a magnetic field vector to generate local magnetic field vector values;

c) measuring an acceleration vector to generate local gravity vector values;

d) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

e) calculating a computed measurement vector from the estimate of sensor orientation;

f) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

g) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate;

wherein the operation of performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error;

wherein implementing the partial correction step to compensate for

measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements;

h) integrating the error estimate;

i) normalizing the integrated error estimate to produce a new estimate of sensor orientation; and

j) repeating steps a)-j), wherein the new estimate of sensor orientation is used for e), calculating a computed measurement vector.

Claims 20 (withdrawn): The method of Claim 15 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function comprises using time weighted filtering.

Claim 21 (withdrawn): The method of Claim 15 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function comprises using a Gauss-Newton iteration.

Claim 22 (withdrawn): The method of Claim 15 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate includes:

measuring an angular velocity of the sensor to generate angular rate values;

integrating the angular rate values;

normalizing the integrated angular rate values to produce an estimate of sensor orientation derived from the angular rate values; and

using the estimate of sensor orientation derived from the angular rate values to correct for time lag.

Claim 23 (withdrawn): A method of tracking the orientation of a sensor, the method comprising:

a) providing a starting estimate of sensor orientation quaternion;

b) measuring a magnetic field vector to generate local magnetic field vector values;

c) measuring an acceleration vector to generate local gravity vector values;

d) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

e) calculating a computed measurement vector from the estimate of sensor orientation, using quaternion mathematics;

f) comparing the measurement vector with the computed measurement vector to generate an 6x1 error vector that defines a criterion function;

g) performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate;

h) integrating the quaternion error estimate; and

i) normalizing the integrated quaternion error estimate to produce a new estimated sensor orientation quaternion;

j) repeating steps a)-j), wherein the new estimated sensor orientation quaternion is used for e), calculating a computed measurement vector.

Claim 24 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate comprises minimizing the criterion function without calculating the criterion function.

Claim 25 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate comprises multiplying the 6x1 error vector by the function $[X^TX]^{-1}X^T$.

Claim 26 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate further includes implementing a partial correction step to compensate for measurement error.

Claim 27 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate comprises using a time weighted filtering system.

Claim 28 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate comprises using a Gauss-Newton iteration.

Claim 29 (currently amended). ~~The method of Claim 26 wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements~~ A method of tracking the orientation of a sensor, the method comprising:

a) providing a starting estimate of sensor orientation quaternion;

b) measuring a magnetic field vector to generate local magnetic field vector values;

c) measuring an acceleration vector to generate local gravity vector values;

d) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

e) calculating a computed measurement vector from the estimate of sensor orientation, using quaternion mathematics;

f) comparing the measurement vector with the computed measurement vector to generate an 6x1 error vector that defines a criterion

function;

g) performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate;

wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate further includes implementing a partial correction step to compensate for measurement error;

wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements;

h) integrating the quaternion error estimate;

i) normalizing the integrated quaternion error estimate to produce a new estimated sensor orientation quaternion; and

j) repeating steps a)-j), wherein the new estimated sensor orientation quaternion is used for e), calculating a computed measurement vector.

Claim 30 (withdrawn): The method of Claim 23 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function and outputs a 4x1 quaternion error estimate includes:

measuring an angular velocity of the sensor to generate an angular rate quaternion;

integrating the angular rate quaternion;

normalizing the integrated angular rate quaternion to produce an estimate of sensor orientation quaternion derived from the angular rate quaternion; and

using the estimate of sensor orientation quaternion derived from the angular rate quaternion to correct for time lag.

Claim 31 (withdrawn): A sensor apparatus comprising:

a magnetic field detector configured to measure a magnetic field vector and output a local magnetic field vector signal; and

an acceleration detector configured to detect a local gravitational field vector and output a local gravitational field vector signal.

Claim 32 (withdrawn): The sensor of Claim 31, further includes an angular velocity detector configured to detect an angular velocity vector of the sensor and output angular velocity signal.

Claim 33 (withdrawn): The sensor of Claim 32 wherein, the angular rate detector comprises a three-axis angular velocity detector; the magnetic field detector comprises a three-axis magnetometer; and the acceleration detector comprises a three-axis accelerometer.

Claim 34 (withdrawn): The sensor of Claim 31 wherein the sensor includes at least one processor that receives and processes the signals from the magnetic field detector and the acceleration detector to determine the orientation of the sensor apparatus.

Claim 35 (withdrawn): The sensor of Claim 32 wherein the sensor includes at least one processor that receives and processes the signals from the magnetic field detector, the acceleration detector, and the signal from the angular velocity detector, wherein the at least one processor is configured to determine the orientation of the sensor.

Claim 36 (withdrawn): A system for tracking the posture and orientation of body, the system comprising:

the body having mounted thereon at least one sensor;

each sensor including a magnetometer for measuring a magnetic field vector and a acceleration detector for measuring a body acceleration vector, and

at least one processor for receiving input from the magnetometer and

acceleration detector and using said input to calculate a local magnetic field vector and a local gravity vector and to determine the orientation of the body.

Claim 37 (withdrawn): A system as in Claim 36 wherein the at least one processor is configured input the body orientation information into a synthetic environment; and

wherein the system further includes a display for displaying the position and orientation of the body with respect to the synthetic environment.

Claim 38 (withdrawn): A system as in Claim 37 wherein the at least one processor is configured to correct for the offset between sensor coordinates and body coordinates.

Claim 39 (withdrawn): A system as in Claim 36 wherein each sensor further includes an angular velocity detector for measuring a body angular velocity vector.

Claim 40 (withdrawn): A system as in Claim 39 wherein the at least one processing is configured input the body orientation information into a synthetic environment; and

wherein the system further includes a display for displaying the position and orientation of the body with respect to the synthetic environment.

Claim 41 (withdrawn): A system as in Claim 40 wherein the at least one processor is configured to correct for the offset between sensor coordinates and body coordinates.

Claim 42 (withdrawn): A system as in Claim 36 wherein the body comprises an articulated rigid body having a plurality of segments interconnected by at least one joint and wherein each segment has mounted thereon at least one sensor.

Claim 43 (withdrawn): A system as in Claim 39 wherein the body comprises an articulated rigid body having a plurality of segments interconnected by at least one joint and wherein each segment has mounted thereon at least one sensor.

Claim 44 (withdrawn): A method of determining the direction of a local gravity vector with an acceleration detector, the method comprising:

moving the acceleration detector from a start point to an end point over a time period;

taking measurements of the total acceleration vector during the time period;

weighted summing the measurements of the total acceleration vector over the time period; and

calculating gravity vector values using the weighted sum of the total acceleration measurements.

ADDED NEW CLAIMS

Claim 45 (new): A method of tracking the orientation of a sensor, the method comprising:

a) measuring a magnetic field vector to generate local magnetic field vector values;

b) measuring an acceleration vector to generate local gravity vector values;

c) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

d) calculating a computed measurement vector from the estimate of sensor orientation

e) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function; and

f) performing a mathematical operation that results in the minimization of the criterion function usingreduced order Gauss-Newton iteration.

Claim 46 (new). A method of tracking as in Claim 45 wherein the reduced order Gauss-Newton iteration of Claim I takes into account that there are only three independent elements in a quaternion.

Claim 47 (new). A method of tracking as in Claim 45 wherein the reduced order Gauss-Newton iteration requires the inversion of a matrix with a dimensionality of no more than 3 x 3.

Claim 48 (new). A method of tracking as in Claim 45 wherein the reduced order Gauss-Newton iteration utilizes a reduced order 6 x 3*X* matrix entirely composed of elements of the computed measurement vector.

Claim 49 (new). A method of tracking the orientation of a body limb segment of a tracked subject compared to sensor orientation, comprising:

a) determining a correction to compensate for the difference

between sensor coordinates and body limb segment coordinates;

b) placing the tracked subject in a single predetermined reference position;

c) wherein the body limb segment axes are aligned with corresponding Earth-fixed axes or differ by a known offset; and

d) wherein the correction found while the tracked subject is in the predetermined reference position consists of the inverse of the orientation reported by the sensor and the inverse of any known offset.

Allowance and passage to issue at an early date are respectfully requested.

Respectfully submitted,

ERIC R. BACHMANN
ROBERT B. McGHEE
XIAOPING YUN
MICHAEL J. ZYDA
DOUGLAS L. McKINNEY

Date: April 8, 2004

By: Donald E. Lincoln
DONALD E. LINCOLN
Attorney for Applicants
Registry No. 34,213
Phone: (831) 656-3356

Superintendent
Naval Postgraduate School
Office of Counsel, Code 00C
1 University Circle, Rm 131
Monterey, CA 93943-5001
(831) 656-3356